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Compressive Strain Behaviour under Different Strain Rates in Multi-Walled Carbon Nanotubes-Polycarbonate Composites

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Abstract

Polycarbonate (PC) based composites were fabricated with different concentrations of Multi Walled Carbon Nanotubes (MWCNTs) and were subjected to dynamic impact loading using Split Hopkinson Pressure Bar (SHPB). Impact tests using this instrument were performed under varying strain rates ranging from 1096 to 4017/s on pure PC samples and samples with 0.1, 0.5 and 1% by weight of MWCNT concentrations in PC. A comparison of maximum strains produced in these samples due to different strain rates was done. It was found that the maximum strain produced for every sample increases with increase in strain rate. Maximum strain is a measure of the toughness and deformation of the sample which increases as strain rate increases.

Keywords: Strain rate; Maximum strain; Polycarbonate; Carbon nanotubes

Introduction

Stress behavior of materials at high strain rates is a very important parameter for shock and energy absorbing related applications. However, along with stress, it is very important to see how much deformation the sample undergoes when it experiences heavy impact loads. The maximum strain that a material undergoes gives a measure of the energy required for the material to undergo permanent fracture, in other words it gives the measure of its toughness. For any practical shock load related application, the specimen which undergoes such heavy impact must be capable of absorbing the load and its deformation also becomes important to analyse its repeated use. Shielding specimen can be one time use substances or can be used multiple times also depending upon their state after first time use. However, dynamic impact loads generally cause a permanent strain or deformation in the specimen. Moreover, various composites exhibiting properties to absorb heavy impact loads must also be studied for the maximum strain they undergo before failing because if the space where that specimen is installed does not permit this deformation, then it can escalate the damage to other parts of the host machinery. So, it becomes imperative to evaluate the dimensional change caused in samples.

Over the past few decades, materials have exhibited similar behavior of increased strain when they undergo higher strain rates. Ever since the synthesis of Carbon Nanotubes (CNTs) [1] and study that followed exploring mechanical and structural properties of CNTs [2-4], there has been wide ranging interests in scientific and engineering communities to exploit these for varying applications. The unusual mechanical strength of the carbon nanotubes revealing them as about 100 times stronger than steel motivates to fabricate and modify useful materials which are cheaply available in bulk form by embedding in these carbon nanotubes in various forms to make composites which have desired mechanical properties. For low strain rate range, Weeks et al. [5], has shown that as strain rate increases from 10 μ/s to 100,000 μ/s on AS4 thermoplastics off axis composites the strain behavior shows a non-linear behavior. The maximum strain varies from 1.7% to 2.7% in the above strain range. Renliang et al. [6], used the specimen as granite and marble and performed impact test using SHPB. It was found that stress strain behavior was linear for a small strain range and beyond that a non-linear pattern was reported. The high strain rate has been measured as high impact velocity and as velocity is increasing the maximum strain is also increasing from 100×10^{-4}% to 250×10^{-4}%. Another elastic material which was tested using SHPB by Ramezani et al. [7]. It showed the stress strain pattern for strain rates of 180/s, 230/s, 300/s and 350/s. The maximum stress for this specimen kept increasing with increase in strain rate and maximum strain also increase from 0.6% to 0.8%. Tension test was performed on polycarbonate for strain rates in the range of 370/s to 1700/s by Kan Cao et al. [8], and again an increase of maximum strain was reported. Siviour et al. [9], performed compression impact tests on polycarbonates and polyvinylidene diflouride for strain rates of nearly 10^4/s at different temperatures. Maximum strains for these samples also increased with strain rate. Chen et al. [10], performed similar tension and compression tests on PMMA and Epon 828/T-403 using SHPB. The results reported do not show much variation on strain due to variation in strain rates which are in the order of 1000/s to 5000/s.

In an earlier study, we had fabricated PC-MWCNT composite samples and studied their dynamic impact resistance behavior using SHPB [11]. From the same experiments, we hereby study the effect on concentration on the strain produced due to dynamic impact loading.

Results and Discussion

The impact loading was performed for various strain rates. Strain rates in the range 2000/s to 2600/s is applicable in defence related applications [12], so the performance of samples within this range needs to analysed. Maximum and elastic limit strains which the samples exhibited in the range of low strain rates (nearly 1500/s) and high strain rates (nearly 3000/s) have been depicted in table 1. It shows that both elastic limit strain and maximum strain increase for every sample irrespective of the sample concentration as strain rate increases.

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Strain(s^{-1})	Elastic limit strain(%)	Maximum strain(%)
For Pure PC sample		
1576	8	45
2778	10	112
3300	10	112
3900	16	229
For 0.1% MWCNT-PC composite		
2609	10	99
2778	10	108
3200	12	144
For 0.5% MWCNT-PC composite		
2032	8	66
2186	10	73
2768	10	108
2845	10	113
For 1.0% MWCNT-PC composite		
1643	9	53
2547	10	92
2926	10	116
3133	12	136

Table 1: Variation of elastic limit strain and maximum strain for different compositions at various strain rates.

Previous paper studies indicated that major increase in stress resistance for pure PC takes place for samples with 0.5% MWCNTs in PC. Figures 1-3 indicate the stress-strain results for pure PC, 0.1% MWCNT-PC and 0.5% MWCNT-PC under different strain rates graphically. The maximum stress for each composition does not show any uniform variation with strain rate for every composition. However, for our present study, since deformation (strain) is the main focus we observe that as strain rate increases the maximum strain for every composition increases before being crushed. Considering, that if any equipment is complex with several small important devices attached in a very limited space arrangement and it gets exposed to heavy dynamic loading then the impact absorbing or protective shield has to not only absorb the heavy impact but also assure that its deformation does not disturb the other small devices. So, owing to space limitations such studies become imperative.

From the figures 1-3, it becomes evident that PC based samples can deform to a large extent as the dynamic impact load increases which is a similar behavior to various other materials like AS4 thermoplastics, granite, marble etc [5-8].

Figure 4 indicates the strain behavior for the four main concentrations of pure PC, 0.1% MWCNT-PC and 0.5% MWCNT-PC. Addition of small quantities of MWCNTs in PC enhances the stress [11] but it does not increase the maximum strain. This is evident from figure 4 as the samples with or without MWCNTs does not show much strain variation at high strain rates. These materials after crossing the elastic limit tend to lose their strength and as a result start deforming very rapidly even if the applied external load is reduced. Therefore, during dynamic loading maximum stress and maximum strain become important points. Although, MWCNTs do not enhance the maximum strain but their embedding in PC enhances the maximum stress due to which their application for such applications becomes critical.

Summary and Conclusion

This paper highlights the role of strain rate on the stress-strain behavior of MWCNT-PC composites with specific reference to maximum strain of the specimen. In an earlier paper, mechanical properties at a given strain rate of these composites were presented. Whether the pure PC is embedded with MWCNTs or not, the maximum strain increases with increase in strain rate.

Small quantities of MWCNTs when embedded in pure PC enhance its impact absorption capacity by nearly 10-15% [11]. Apart from this, the deformation that takes place when these specimens are subjected

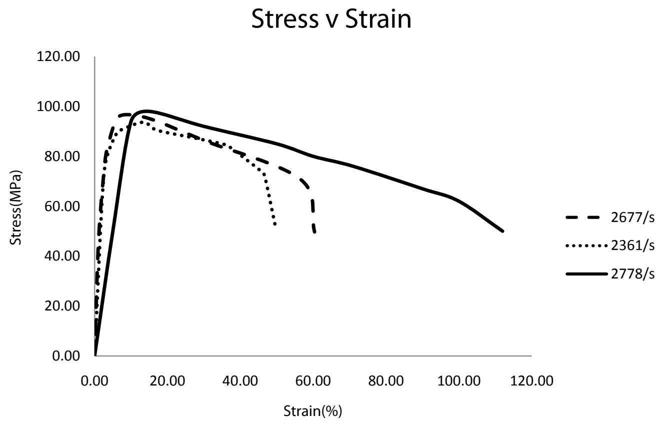

Figure 1: Stress-Strain variation for pure PC under different strain rates.

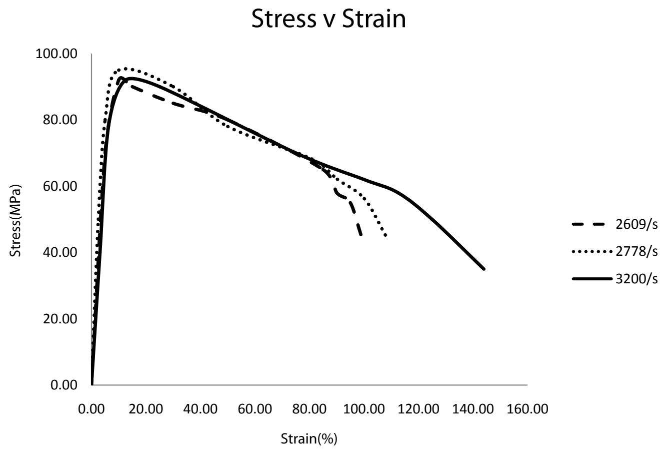

Figure 2: Stress-Strain variation for 0.1% MWCNT-PC under different strain rates.

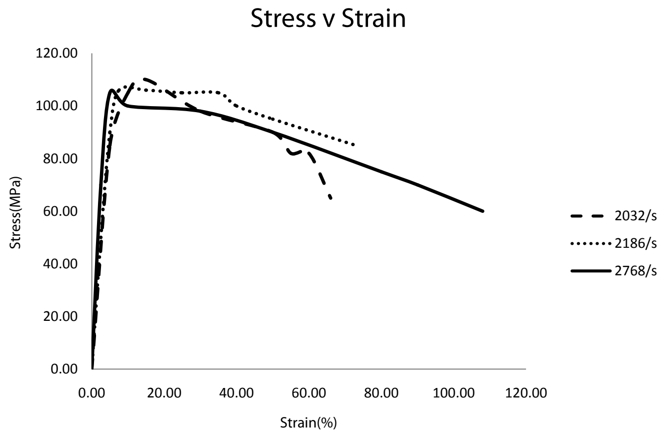

Figure 3: Stress-Strain variation for 0.5% MWCNT-PC under different strain rates.

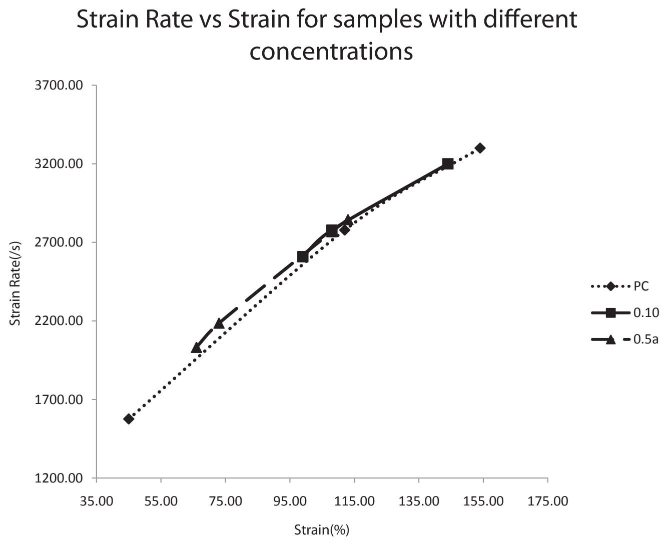

Figure 4: Variation of strain rate with strain for pure PC, 0.1% MWCNT-PC and 0.5% MWCNT-PC.

to such high impact loads also becomes a matter of concern. When the impact load process is over, this specimen deforms and in the final state may get even broken or crushed. However, during deformation it dimensional change may cause interference to various other devices installed around, which can escalate the damage caused by the impact. So, the specimen that is installed for protection from heavy impact load must conform to the space around it and its deformation must also be ascertained. More samples and data is required to see when the strain starts decreasing or remains unchanged with increase in strain rate, as the limit has to be explored.

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